INVESTIGATION OF ION EFFECTS IN THE SRRC STORAGE RING BY VENTING H_2 GAS

J. C. Lee, M. H. Wang, G. Y. Hsiung, K. T. Hsu and J. R. Chen
SRRC, Hsinchu Science-Based Industrial Park, Hsinchu, Taiwan, ROC

Abstract

The instabilities produced by ions are one of the issues in the electron storage ring. At SRRC, H_2 ion is the dominate species. Comparing with other species, H_2 ions are uneasy to be trapped from the conventional ion points of view for its small atomic mass. While H_2 ions could introduce fast beam ion instabilities. In order to understand more details of the ion produced instabilities in the ring, H_2 gas was intentionally vented into the ring chamber. In this paper, the instabilities which relate to the H_2 ions are described and the physics is also discussed.

1 INTRODUCTION

As ions are trapped by the electron potential, the beam and the ions are mutually interacted with each other and perform two beam oscillations. The linear equations of motion are

$$y_e^{"}(s,t)+\omega_\beta^2 y_e(s,t) = \frac{2\lambda_i r_e}{\gamma}\frac{y_i(s,t)-y_e(s,t)}{\sigma_y(s,t)(\sigma_y(s,t)+\sigma_x(s,t))} \quad (1)$$

$$\ddot{y}_i(s,t)+\omega_i^2 y_i(s,t) = \omega_i^2 y_e(s,t) \quad (2)$$

in which the subindex e and i indicate the motion of electron and ion respectively. The derivative of $y_e^{"}$ is w.r.t. coordinate s and $\ddot{y}_i$ to time. Also λ_i is ion charge density, γ the electron beam energy, $\sigma_{x,y}$ the horizontal or vertical beam size and $\omega_{\beta,i}$ the angular frequency for the beam and ions respectively.

From equation (1) it is clear that the driven force from ions is proportional to the trapped ion density and is inversely proportional to the beam size and beam energy. Equation (2) can be treated with the help of periodic passing of the beam bunches to obtain stable conditions of ion motion. From the stable conditions ions trapped by beam potential can be investigated. It dependents on the operation conditions and ion atomic mass. For the smaller atomic mass and the bigger empty gap the less ion trapping in the ring. The ring operated with a big enough empty gap to avoid ion trapping is the well known method[1,2,3,4] in the world. While there is the possibility for the massive ions to be trapped. It is also not easy to control the ion species in the ring. For the SRRC storage ring even H_2^+ ion has the possibility to be trapped[5]. While unfortunately the H_2 ion is the dominate species in the SRRC storage ring. This stimulated the studies by increasing the trapped density of $H_2^{[+]}$ ion from venting H_2 gas into the ring.

There is another kind of ion produced instability which is called fast beam ion instabilities[6,7]. This kind of instability is very fast such that the ions accumulated by the previous bunch could affect the next coming bunches. Due to the instrument issues, no much measurements were down about this kind of instability. While some discussions are given in the paper.

2 VENTING SETUP

The venting port is around 140mm down steam Q_2 quadrupole magnet in the R6 section. High purity H_2 gas was vented into the ring by using the electropolished tube. For vacuum consideration, TMP, ion pump and NEG were installed in the bottom of the venting port. During the studies the pressure was increased across a local area, dependents on how much venting, and no pressure increasing outside this local area. The H_2 gas was intentionally increased in the experiment and the other species were neglected small compared with the population of H_2. For the normal operation the averaged vacuum pressure is around 0.3 ntorr and is around 0.7 ntorr in the local vented area. While the local pressure is under 1x10^{-7} ntorr in the local vented area for most cases as H_2 gas vented.

3 EXPERIMENTAL MEASUREMENT

The experiments were all performed at 1.5GeV. During the experiments the global orbit feedback and transverse damper systems are off to avoid unexpected driven on the beam. But the large positive chromaticities are set to damp instabilities in reasonable levels. The experiment was first performed at 122mA with a pattern of big enough empty gap, 120/200 buckets filled, to avoid conventional ion trapping (case A). The beam is stable for there are no transverse peaks. Then the H2 gas was vented into the ring up to 60 ntorr in the local vented area. The coherent oscillation peak in the vertical plane showed up. By measuring the slow betatron sideband at each revolution, the coherent spectrum is obtained, as shown in figure 1. This coherent peak has the periodic structure with the period of revolution. This peak frequency is identified to the H_2 ion oscillation frequency according to[6]

$$\omega_i = \left(\frac{4N_e r_p C^2}{3L_{sep}\sigma_y(\sigma_x+\sigma_y)A}\right)^{1/2} \quad (3)$$

where N_e is the number of electrons per bunch, r_p the classical proton radius, A the atomic number and L_{sep} the separation of bunches. The vertical beam size is dilute a little

0-7803-5573-3/99/$10.00@1999 IEEE.

bit but no significant changing in horizontal. These results are similar to that of ALS fast ion observations[7].

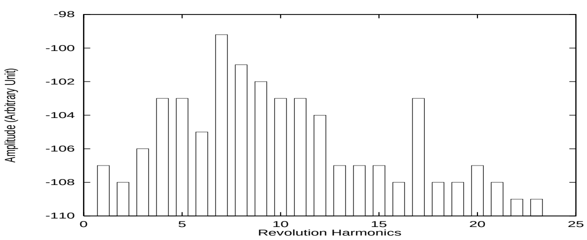

Figure 1: Coherent spectrum corresponding to the H_2^+ ion oscillation frequency.

In order to understand more details, a pattern with all of the RF buckets filled was employed in the studied at 200mA (case B). In this case the transverse coherent peaks were showed up, horizontally and vertically, and the beam pulsated. The betatron tune peak shifted randomly across a range of 3kHz. These features indicate the convention ion effect plays an important role in this all buckets filled case. The H_2 gas was then intentionly vented into the ring up to around 70 ntorr in the local vented area. It is found that a) there are still the transverse coherent peaks and pulsation on beam size, b) the betatron tune peak is also shifted in a more wilder range, and c) the frequency of the coherent peaks are almost the same as that of the before venting one under almost the same beam size which is pulsated on both cases, d) the vertical beam size increased as the increasing of H_2 gas but no significant variation in horizontal, as shown in figure 2. The fluctuation on the vertical beam size shows the instability in the vertical plane.

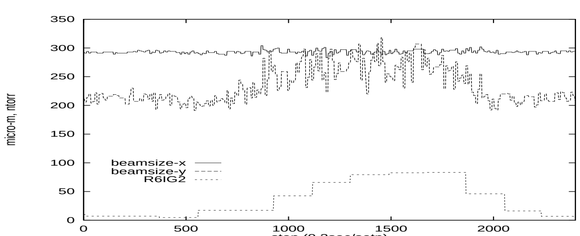

Figure 2: Beam size variation versus the vacuum pressure in the local vented area.

Form the results in case B it can conclude that the coherent peaks are produced by the H_2 ions before and during venting H_2 gas. It is also verified by the theoretical calculation of H_2^+ oscillation frequency from ring parameters.

The experiments were reproduced with a big empty gap in the pattern, around 125/200 buckets filled, to have vertical coherent oscillation peaks before venting H_2 gas (case C). The results of venting H_2 gas are the same as that of all of RF buckets filled one but with the less strength in coherent peaks. The tune is also shifted in a range of 2KHz for without venting one and of 2.5KHz for venting H_2 gas due to instabilities. The averaged results of these shifted tune peaks give the 'averaged' tune spread for the instability, as shown in figure 3 for venting and without venting.

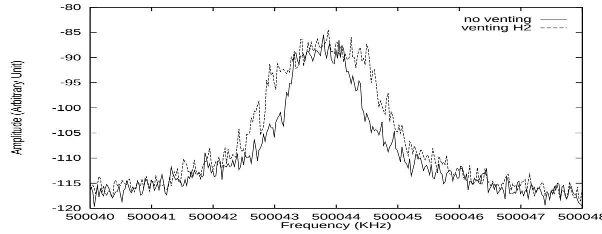

Figure 3: Vertical tune spread with and without venting H_2 gas.

From conventional points of view, case A has no conventional ion effects before venting H_2 gas. The instabilities during venting is coming from fast beam ion effects. While if we compare the venting results of case A with case B, there are no big differences between two cases except the coherent oscillation amplitude is bigger for case B, in which the conventional ion effect is important. From the similar results of cases B and C it indicates the conventional ion effects play an important role in these two cases. Also from the facts of venting H_2 gas and the frequency information of the coherent oscillation, it concludes that the H_2 ion is the suspicion of the ion instability for case C without venting. For the routine operation in SRRC storage ring, the empty gap is smaller than that of case C, about 20 to 40 gap. While the transverse oscillation behavior in routine operation is similar to that of case C when the feedback systems are off. Hence we arrives the following understandings form above results. There are a) the H_2 ion is the dominate source for the conventional ion instability in SRRC storage ring, which is consistent with our previous estimation[5], b) the increased density of H_2 gas (or ions) is to enhance the instability, c) the vertical beam size increasing and no increasement in horizontal from venting H_2 gas are common features for the fast beam ion (case A) and conventional ion (cases B and C) effects.

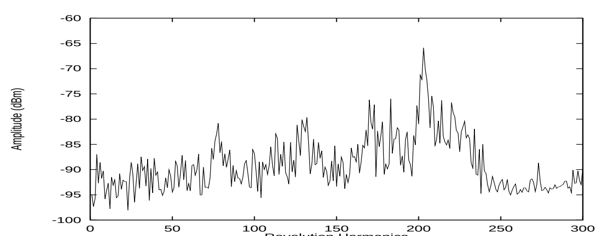

Figure 4: Measurements of the vertical slow sideband for 95/200 filled pattern at 156mA as H_2 gas vented.

While the H_2 ion is very easy to escape from trapping for its small atomic mass. In order to understand more details, the partial pressure of H_2 was increased further by venting more gas into the ring, which was operated at 156mA with around 95 buckets filled (case D). There were no coherent peaks before venting. It is found that lots of the transverse peaks show up, as shown in figure 4, besides the coherent peak of H_2^+ oscillation frequency, about 9.9MHz, as the local pressure increased up to 5×10^{-7} torr. The empty gap of case D is smaller than that of case A. Therefore there is no conventional ion effects also. While the results are quite different during venting. The additional peaks shown in figure 4 would not coming from other species for the frequency of these additional peaks are larger than the coherent peak of H_2^+ and other species will give smaller frequency peaks for the large atomic mass.

The electric potential produced by the electron beam would not be changed by the vacuum pressure. That means the trapping ability is almost the same for different pressure. If the pattern is filled such that the beam can accumulate ions, then the instabilities enhanced by the pressure is reasonable for more ions are trapped in the higher vacuum pressure. But if empty gap is big enough to avoid trapping why there are additional peaks in high vacuum. One possible answer is that the theory we followed is only linear one. It is valid for small amplitude. For the cases of drastic oscillation, the high order terms need to be included[8]. People could criticized that the ions are trapped in cases A and D since the instabilities could be damped off by the strong chromaticities in the experiments. While since the empty gap is larger than that for trapping this possibility is excluded.

If we investigate what shown in figure 4, there is something like the features of impedance. The idea of impedance provides a trace to follow. The new idea is similar to that of the fast beam ion instability with the ions accumulated by previous bunch does affect on the following coming bunches by the very fast time. But the period of the affect time is larger than the revolution. If we compare this new idea with the physics of impedance from wake field, they are quite similar. The wake force affects on the beam with the help of vacuum chamber. While the ion force is coming from the interaction of beam and ions. If the idea of impedance like behavior is accepted then what shown in figure 4 and the above results are reasonable. Hence we can arrive the following understandings (maybe suspicious only): the ion effects on the beam have some kind of impedance behavior.

4 DISCUSSION

From above experimental results, it clear that the coherent peaks shows up during venting H_2 gas are due to the H_2 ions. By comparing the frequency of the coherent peaks with and without venting H_2 gas it concludes the coherent oscillations appeared in the no venting cases are mainly from the H_2 ion. This is also verified by theoretical calculation of ion frequency from ring operation parameters. From what shown in above experimental results, especially in case C, H_2 ion is the major contributor for the ion instability in SRRC storage ring. For case D with around half buckets filled and no coherent peaks before venting, it would not have conventional ion effects. While there are lots of the coherent peaks besides that of the H_2^+ frequency as the vacuum was increased up to 5x10^{-7} torr by venting H_2 gas. Does these peaks come from the fast beam ion instabilities? However it is assumed the ions will lost in the gap for the fast ion one. Otherwise it is difficult to distinguish the fast ion and the conventional ion effects. While if the impedance idea is introduced for the ion effects this problem can be solved and the behavior shown in figure 4 could be explained also.

This 'impedance like' behavior not only occurs in the high vacuum but also found in the low vacuum. It is found in SRRC storage ring at normal operation vacuum pressure at 1.3 GeV with a all of buckets filled pattern[9]. From these facts it imply that the impedance like behavior could happen as the ion driven force become large. This is understood from the driven term in equation (1), in which less beam energy and high vacuum pressure enhance the driven force. Ring operated with all of the buckets filled will increase the trapping ability. Though the ion could introduce impedance like behavior, while the quantitative measurements are still in progress. In the next step the direct measurement on the impedance will be important.

From the additional peaks show up by the large driven force, it imply there is the rise time issue. The instabilities at some of the frequency could be damped by the radiation damping, chromaticities etc. While the rise time could be faster than above damping mechanism as the driven force increased.

From the experiments the coherent peak of ion frequency shows up first and then the additional peaks as the driven force getting large. These peaks have the periodic structure with the period of revolution. This fact is obvious for the coherent frequency peak of H_2^+. While the theory in conventional ion and fast beam ion instabilities can't explain these coherent modes. Hence the theoretical studies and the further measurements will be important in the future.

5 ACKNOWLEDGEMENT

The author would like to thank J. Chen and H. J. Tsai for the help in data acquisition.

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